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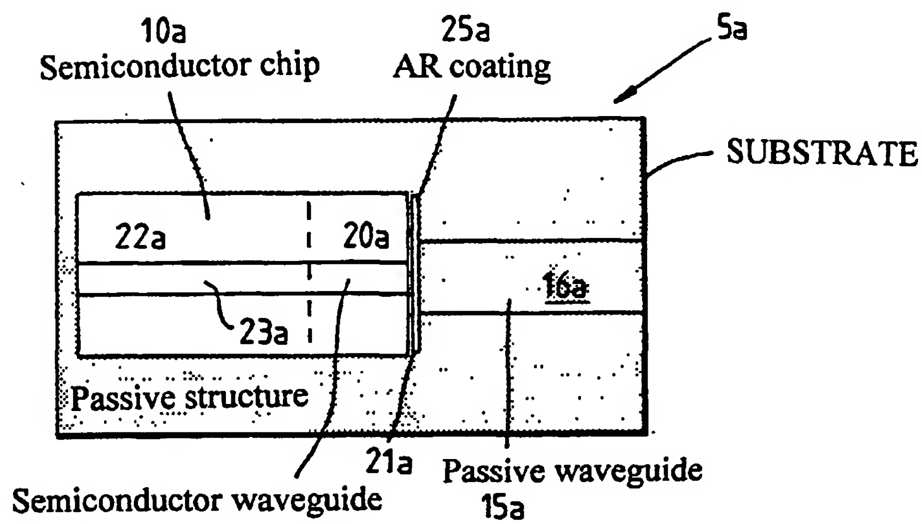
(54) Title: IMPROVED INTEGRATED OPTICAL DEVICE



(57) Abstract: There is disclosed an improved integrated optical device (5a-5g) providing first and second devices (10a-10g; 15a, 15e), optically coupled one to the other and formed in first and second different material systems, one of the first or second devices (10a-10g, 15a, 15e) having a Quantum Well Intermixed (QWI) region (20a, 20g) at or adjacent a coupling region between the first and second devices (10a-10g; 15a, 15e). The first material system may be a III-V semiconductor based on Gallium Arsenide (GaAs) or Indium Phosphide (InP), while the second material system may be Silica (SiO_2), Silicon (Si), Lithium Niobate ($LiNbo_3$), a polymer, or glass.

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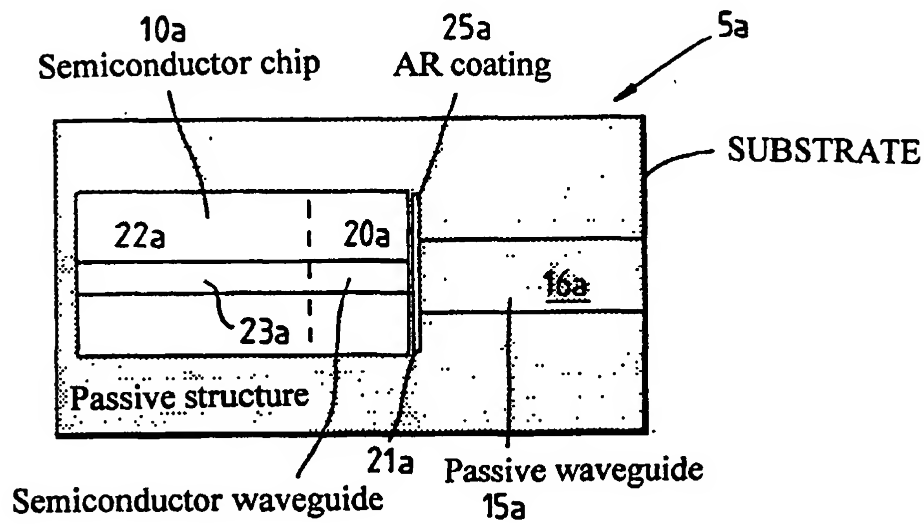

(57) **Abstract:** There is disclosed an improved integrated optical device (5a-5g) providing first and second devices (10a-10g; 15a, 15e), optically coupled one to the other and formed in first and second different material systems, one of the first or second devices (10a-10g, 15a, 15e) having a Quantum Well Intermixed (QWI) region (20a, 20g) at or adjacent a coupling region between the first and second devices (10a-10g; 15a, 15e). The first material system may be a III-V semiconductor based on Gallium Arsenide (GaAs) or Indium Phosphide (InP), while the second material system may be Silica (SiO_2), Silicon (Si), Lithium Niobate ($LiNbo_3$), a polymer, or glass.

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IMPROVED INTEGRATED OPTICAL DEVICE

FIELD OF INVENTION

This invention relates to an improved integrated optical device or optoelectronic device, and particularly to hybrid integration of devices formed in different material systems. For example, hybrid integration of III-V semiconductor devices with passive waveguide structures.

BACKGROUND TO INVENTION

Hybrid integration of III-V semiconductor components with passive waveguides is of increasing importance as a method of increasing the functionality of integrated optical and photonic systems. Applications include: optical communication systems, optical sensing applications, and optical data processing.

A fundamental problem in hybrid integration is that the semiconductor element has a higher refractive index than the passive waveguide. In the case of a III-V semiconductor component integrated on a planar Silica (SiO_2) platform, the refractive indices are typically around 3.6 for the semiconductor and 1.5 for the Silica. This refractive index difference causes a number of problems, eg there is a high reflection coefficient at the interface between the two devices, and the mode size in each device is different. Both of these effects result in a loss in optical power and reduced coupling efficiency between the two devices, and scattering of light, and undesirable reflections.

It is an object of the present invention to obviate or at least mitigate one or more of the aforementioned problems in the prior art.

Further objects of various embodiments of the present invention include:

enablement of hybrid integration to be carried out, while ensuring good mode matching between active and

passive sections;

ease of manufacture;

low loss coupling between active and passive sections.

SUMMARY OF INVENTION

According to a first aspect of the present invention there is provided an integrated optical device providing first and second devices optically coupled one to the other and formed in first and second different material systems, at least one of the first or second devices having a Quantum Well Intermixed (QWI) region at or adjacent a coupling region between the first and second devices.

Quantum Well Intermixing (QWI) permits a postgrowth modification to the absorption edge of Multiple-Quantum Well (MQW) material, and therefore provides a flexible, reliable, simple, and low-cost approach compared to competing integration schemes such as selective area epitaxy or selective etching and regrowth.

Quantum Well Intermixing (QWI) provides a means of tuning an absorption band edge controllably in Quantum Well (QW) structures, and may be utilized to fabricate low-loss optical interconnects between monolithically integrated optical devices or integrated optoelectronic devices.

The first material system may be a III-V semiconductor material system. The III-V semiconductor material may be selected from or include one or more of: Gallium Arsenide (GaAs), Aluminium Gallium Arsenide (AlGaAs), Indium Phosphide (InP), Gallium Arsenide Phosphide (GaAsP), Aluminium Gallium Arsenide Phosphide (AlGaAsP), Indium Gallium Arsenide Phosphide (InGaAsP), or the like.

The second material system may be a non III-V semiconductor material. The second material system may be selected from: Silica (SiO_2), Silicon (Si), Lithium Niobate ($LiNbO_3$), a polymer, a glass, or the like any of which may be doped with optically active material.

The first device may be or include an active device component, such as a laser diode, light emitting diode

(LED), optical modulator, optical amplifier, optical switch, or switching element, optical detector (eg photodiode), or the like. The first device may also include a passive device compound such as a passive waveguide.

The second device may be or include a passive component such as a passive waveguide.

Preferably, the coupling region provides means for at least substantially mode matching between the first and second devices.

In one arrangement the first device provides the Quantum Well (QW) intermixed region.

In the one arrangement the mode matching means may comprise a waveguide provided in the first device which waveguide may be a "tapered" waveguide providing a linear change in width, a non-linear change in width, and/or a "periodic" or "a-periodic" segmentation.

Preferably, the coupling region provides anti-reflection means at or near an interface between the first and second devices.

The anti-reflection means may comprise or include an anti-reflection coating on a facet of the first device provided at the interface between the first and second devices.

The anti-reflection means may also comprise or include facets of the first and second devices provided at the interface between the first and second devices, the facets being formed at an (acute) angle to an intended direction of optical transmission. The facets may therefore be referred to as "angled facets".

In a preferred embodiment a first waveguide section in the first device and preferably also a second waveguide section in the second device is/are bent.

The integrated optical device may be adapted to operate in a wavelength region of 600 to 1300nm or of 1200 to 1700 nm.

According to a second aspect of the present invention, there is provided an integrated optical circuit,

optoelectronic integrated circuit, or photonic integrated circuit including at least one integrated optical device according to the first aspect of the present invention.

According to a third aspect of the present invention there is provided an apparatus including at least one integrated optical device, the at least one integrated optical device providing first and second devices optically coupled one to the other and formed in first and second different material systems, one of the first or second devices having a Quantum Well Intermixed (QWI) region at or adjacent a coupling region between the first and second devices.

According to a fourth aspect of the present invention there is provided a method of providing an integrated optical device having hybrid integration of first and second devices formed in first and second different material systems comprising:

providing one of the first or second devices with a Quantum Well Intermixed (QWI) region at or adjacent a coupling region between the first and second devices.

The Quantum Well Intermixed (QWI)region may be formed from a number of techniques, but preferably by a universal damage induced technique, Impurity Free Vacancy Diffusion (IFVD).

In a preferred embodiment, the Quantum Well Intermixed (QWI) region may be formed in the first device by intermixing a Quantum Well(s) (QW) in a core optical guiding layer of the first device, eg by Impurity Free Vacancy Diffusion (IFVD).

When performing IFVD upon a top cap layer of the a III-V semiconductor material comprising the first device is deposited a dielectric, eg SiO_2 layer or film. Subsequent rapid thermal annealing of the semiconductor material causes bonds to break within the semiconductor alloy, eg Gallium ions or atoms which are susceptible to Silica (SiO_2), to dissolve into the Silica sc as to leave vacancies in the cap layer. The vacancies then diffuse through the

semiconductor material inducing layer intermixing, eg in the Quantum Well(s) (QW).

IFVD has been reported in "Quantitative Model for the Kinetics of Compositional Intermixing in GaAs - AlGaAs Quantum - Confined Heterostructures", by Helmy *et al*, IEEE Journal of Selected Topics in Quantum Electronics, Vol 4, No 4, July/August 1998, pp 653 - 660, the content of which is incorporated herein by reference.

According to a fifth aspect of the present invention there is provided a first device according to the first aspect of the present invention.

BRIEF DESCRIPTION OF DRAWINGS

Embodiments of the present invention will now be described, by way of example only, and with reference to the accompanying diagrams, which are:

Figure 1(a)	a schematic plan view of a first semiconductor chip integrated with a passive photonic integrated circuit (PIC) according to a first embodiment of the present invention;
Figure 1(b)-(d)	schematic plan views of second, third and fourth semiconductor chips integratable with a passive photonic integrated circuit (PIC) similar to or the same as that of Figure 1(a) according to the present invention;
Figure 2(a)	a schematic plan view of a fifth semiconductor chip according to the present invention;
Figure 2(b)	a schematic plan view of the fifth semiconductor chip of Figure 2(a) integrated with a passive photonic

integrated circuit (PIC) according to a fifth embodiment of the present invention;

Figure 3 a schematic cross-sectional end view showing a possible layer structure of a semiconductor chip according to a sixth embodiment of the present invention;

Figure 4 a schematic perspective view from one end, above and to one side of the semiconductor chip of Figure 3;

Figure 5 a schematic perspective view from one end, above and to one side of a semiconductor chip according to a seventh embodiment of the present invention.

DETAILED DESCRIPTION OF DRAWINGS

Referring initially to Figure 1(a) there is illustrated an integrated optical device, generally designated 5a, according to a first embodiment of the present invention and providing the first and second devices 10a, 15a respectively, the first and second devices 10a, 15a being optical coupled one to the other and formed in first and second dis-similar material systems, at least one of the first or second devices 10a, 15a having a Quantum Well Intermixed (QWI) region 20a at or adjacent a coupling region 21a between the first and second devices 10a,15a.

In this embodiment the first materials system is a III-V semiconductor material system based on either Gallium Arsenide (GaAs) or Indium Phosphide (InP). For example the III-V semiconductor material may be selected or include one or more of: Gallium Arsenide (GaAs), Aluminium Gallium

Arsenide (AlGaAs), and Indium Phosphide (InP), Gallium Arsenide Phosphide (GaAsP), Aluminium Gallium Arsenide Phosphide (AlGaAsP), Indium Gallium Arsenide Phosphide (InGaAsP), or the like. The integrated optical device 5a may therefore be adapted to operate in the so-called "short" wavelength region of 600 to 1300nm, or the so-called "long" wavelength region of 1200 to 1700 nm.

The second material system is a non III-V semiconductor material and can be selected from Silica (SiO_2), Silicon (Si), Lithium Niobate ($LiNbo_3$), a polymer, glass or the like.

The first device 10a comprises an active device component 22a, selected from a laser diode, light emitting diode (LED), optical modulator, optical amplifier, optical switching element, optical detector (eg photodiode), or the like. The active device component 22a is spaced from the Quantum Well Intermixed (QWI) region 20a, the active device component 22a, and passive QWI region 20a being in optical communication one with the other via a waveguide 23a such as a ridge waveguide.

The second device 15a in this embodiment includes a passive device component in the form of a passive waveguide 16a.

The coupling region 21a provides anti-reflection means at or near an interface between the first and second devices 10a, 15a. The anti-reflection means comprise anti-reflection coating 25a on an end facet on first device 10a provided at the interface between the first and second devices 10a, 15a.

In a modification the anti-reflection means may also comprise facets of the first and second devices 10a, 15a provided at the interface between the first and second devices 10a, 15a, the facets being formed at an acute angle to the intended direction of the optical transmission along waveguides 23a, 16a. In such a modification the facets may be referred to as "angled facets".

Referring now to Figure 1(b) there is illustrated a

second embodiment of a first device 10b comprising part of an optically integrated device according to the present invention, like parts of the device 10b being identified by the same numerals as those for the first embodiment, but suffixed "b". In this second embodiment the waveguide 23b includes a curved portion 30b so as to improve optical coupling between the first device 10b and a second device (not shown), by reduction of reflections at the interface between the first device 10b and the second device.

Referring now to Figure 1(c), there is illustrated a third embodiment of a first device, generally designated 10c, comprising part of an optically integrated device according to an embodiment of a present invention. The device 10(c) is similar to the device 10a of the first embodiment, and like parts are identified by like numerals, but suffixed "c". However, as can be seen from Figure 1(c), the waveguide 23c includes at an end adjacent the coupling region to the second device (not shown) a tapered region 30c which, in use, causes an optical mode "M" transmitted along the waveguide 23c to expand as it traverses the optical waveguide 23c and is output from the first device 10c from the tapered region 30c. The converse of course applies for optical coupling to the first device 10c from the second device (not shown).

Referring now to Figure 1(d), there is shown a fourth embodiment of a first device 10d comprising part of an optically integrated device according to an embodiment of the present invention. The first device 10d is substantially similar to the device 10a of the first embodiment, like parts being identified by like numerals but suffixed "d". However, in the first device 10d, the waveguide 23d includes at an end adjacent a coupling region to a second device (not shown) a curved and tapered region 30b. The first device 10d therefore combines the features of the embodiments of Figures 1(b) and (c).

As will be appreciated, to electrically control the first devices 10a-10d, an electrical contact (metalisation)

will be fabricated cn a surface of the waveguide 23a-23d, while a further electrical contact (metalisation) will be provided on an opposing surface of the device 10a-10b.

It will be appreciated that the modifications shown in the second, third and fourth embodiments 10b, 10c, 10d, seek to improve optical coupling between the first device 10b, 10c, 10d, and a second device (not shown).

It will also be appreciated that the intermixed region 20a to 20b acts to prevent, or at least reduce, optical absorption in the intermixed region 20a-20d adjacent to the coupling region 21a-21d. This is particularly so in the curved tapered waveguide section 30b.

It will further be appreciated that although herein above the waveguide sections 30c and 30d have been referred to as "tapered" regions, the optical mode transmitted therein towards an end of the first device 10c to 10d adjacent to second device (not shown) actually flares.

Referring now to Figures 2(a) and (b), there is illustrated an integrated optical device general designated 5e, according to a fifth embodiment of the present invention. The device 5e provides first and second devices 10e, 15e optical coupled one to the other and formed in first and second different material systems, the first device 10e having a Quantum Well Intermixed (QWI) region 20e adjacent a coupling region 21e between the first and second device 10e, 15e. As can be seen from Figures 2(a) and (b) a waveguide 23e of the first device 10e comprises a tapered curved region 30e adjacent a coupling region 21e between the first and second devices 10e, 15e. Further, an anti-reflection coating 25e is provided within the coupling region 21e on an end facet of the first device 10e. Also, a passive waveguide 16e of the second device 15e is complementarily curved to the portion 30e so as to also assist in optical coupling between the first and second devices 10e, 15e.

Referring now to Figures 3 and 4, there is illustrated a sixth embodiment of a first device generally designated

10f according to the present invention. Like parts of the device 10f are identified by the same numerals as for the device 10a of the first embodiment of Figure 1(a), but suffixed "f".

The device 10f comprises an GaAs substrate 50f, upon which are grown a number of epitaxial layers by known growth technique such as Molecular Beam Epitaxy (MBE) or Metal Organic Chemical Vapour Deposition (MOCVD). The layers comprise a first 0.5μm to 1μm n-doped $Al_{0.50}Ga_{0.50}As$ layer 55f, a second 5μm n-doped $Al_{0.40}Ga_{0.60}As$ layer 60f, a third 0.5μm substantially intrinsic $Al_{0.20}Ga_{0.80}As$ core layer, including a 10nm GaAs Quantum Well (QW), 70f as grown. On the core layer 65f is grown a 1μm p-doped $Al_{0.40}Ga_{0.60}As$ layer 75f, and finally on that layer is grown a p+ doped GaAs capping contact layer 80f. As can be seen from Figure 3, a ridge waveguide 23f is formed in the layers 75f,80f by known photolithographic techniques. Further in this embodiment, a second broader ridge or mesa 35f is also formed in the layers 65f and 60f. Thus the ridge waveguide 23f comprises a primary waveguide while the mesa 35f comprises a secondary waveguide. The device 10f also includes a tapered region 30f on the waveguide 23f. The device 10f, therefore, acts as a mode converter converting a mode from the device 10f coupled to a second device (not shown), or a mode transmitted from the second device to the first device 10f.

As can be seen from Figure 3, contact metallisations 40f and 45f may be provided on a top of ridge 23f and an opposing surface of the substrate 50f. Further, as can be seen from Figure 4, the device 10f includes a Quantum Well Intermixed (QWI) region 20f adjacent to the end of the device corresponding to the tapered region 30f.

In this embodiment the Quantum Well Intermixed (QWI) region 20a is formed in the first device 10f by intermixing the Quantum Well 70f in the layer 60f within the region 20f by Impurity Free Vacancy Diffusion (IFVD). When performing

IFVD upon a top cap layer 80f of the III-V semiconductor material comprising the first device 10f, there is deposited a dielectric, eg Silica ($Silo_2$), layer of film. Subsequent rapid thermal healing of the semiconductor material causes bonds to break within the semiconductor alloy and eg Gallium ions or atoms - which are susceptible to Silica (SiO_2) - to dissolve into the Silica so as to leave vacancies in the cap layer 80f. The vacancies then diffuse through the semiconductor material inducing layer intermixing, eg in the Quantum Well 70f.

Referring now to Figure 5 and to Table 1, there is illustrated a seventh embodiment of a first device generally designated 10g, for use in an optically integrated device according to the present invention. In this sixth embodiment, the first device 10g is fabricated in Indium Gallium Arsenide Phosphide (In In_{1-x} Ga_x As_y P_{1-y}).

The layer structure, grown on an Indium Phosphide (InP) substrate 50g, is shown in Table 1 below.

TABLE 1

Repeats	Thickness (Å)	Material	x	y	Dopant	Type
1	1000	In(x)GaAs	0.53		Zn	p
1	500	Q1/18			Zn	p
1	11500	InP				p
1	50	Q1.05				i
1	2500	InP				
1	800	Q1.1				i
1	500	Q1.8				i
5*	120	Q1.26				i
5*	65	In(x)GaAs	0.53			i
1	120	Q1.26				i
1	500	Q1.18				i
1	800	Q1.1				i
1	50000	Q1.05			Si	n
1	10000	InP (buffer layer adjacent substate)			Si	n

* = Quantum Well (QW)structure

Q = Quaternary, eg Q1.1 = quaternary with 1.1μm bandgap

As can be seen from Figure 5, the first device 10g includes an active waveguide 23g and adjacent to coupling region to a second device (not shown) a tapered region 30g. The waveguide 23g comprises a primary waveguide of the first device 10g, while a further ridge or mesa 35g formed on the device 10g comprises a secondary waveguide. In use, the optical radiation generated within or transmitted from the waveguide 23g towards the tapered region 30g as an optical mode, is caused upon transmission through region

30g from primary optical guiding layer 65g into layer 60g for optical coupling to second device (not shown).

The first devices 5f,5g illustrate a design of regrowth-free tapered waveguide coupler. The small rib waveguide 23f,23g is located on top of a thick lower cladding layer 60f that is partially etched to form mesa waveguide 35f,35g. When the small rib 23f,23g is sufficiently wide, the fundamental optical mode is confined to the small 23f,23g, and there is a high confinement of light within the undoped waveguide core layer 65f, (which itself contains the active Quantum Well layers 75f or intermixed region 20f,20g). At the other extreme, when the small rib 23f,23g is sufficiently narrow, the fundamental mode expands to fill the larger mesa waveguide 35f,35g. This behaviour is a consequence of the design of the waveguide layers. The thicknesses and compositions of the Quantum Well layers at the top of the mesa 35f,35g, and extending under the small rib 23f,23g are such as to prevent guiding of light within these layers if the upper layers comprising the small rib 23f,23g are etched away. The resulting waveguide allows separate optimisation of the optical mode properties of the rib 23f,23g and mesa 35f,35g waveguides at the two extremes of rib width. At large rib widths high-performance device action (such as optical amplification, optical detection, electro-absorptive or electro-refractive modulation) can be achieved. At small rib widths the dimensions of the large mesa 35f,35g and thickness of the lower cladding materials establish the optical mode size of the mesa waveguide for optimum coupling to passive Silica waveguides. The expanded mode can be designed for optimum coupling directly to single mode waveguides in the second (non-semiconductor) material single-mode or to optical fibre, including 1.3 μm and 1.5 μm telecommunication fibre.

The layer structure shown in Figure 3 would be used to make a first device 10f with Quantum Wells resonant with radiation at a wavelength of around 860nm. The structure

shown in Figure 5 would be used to make a first device 10g with Quantum Wells resonant with radiation at a wavelength around 1.5 μm.

It will be appreciated that the embodiments of the invention hereinbefore described are given by way of example only, and are not meant to limit the scope thereof in any way.

It will be particularly understood that the device of the present invention is easier and simpler to manufacture than other devices, and therefore provides the potential of obtaining high quality devices at reduced cost.

It will also be appreciated that in the disclosed embodiments the mode matching means comprised a "tapered" waveguide providing a linear or non-linear change in width, in modified implementations the change in width may be "periodically" or "a-periodically" segmented.

It will further be understood that in this invention, Quantum Well Intermixing (QWI) is used to reduce absorption by the Quantum Well layers within the taper region and so reduce optical losses in the taper region and improve device efficiency.

Finally, it will be appreciated that in a modification the first device may be inverted with respect to the second device, ie the ridge waveguide of the first device may be in contact with, or adjacent, a surface of the second device.

CLAIMS

1. An integrated optical device providing first and second devices optically coupled one to the other and formed in first and second different material systems, at least one of the first or second devices having a Quantum Well Intermixed (QWI) region at or adjacent a coupling region between the first and second devices.

2. An integrated optical device as claimed in Claim 1, where the first material system is a III-V semiconductor material.

3. An integrated optical device as claimed in Claim 2, wherein the III-V semiconductor material includes one or more of: Gallium Arsenide (GaAs), Aluminium Gallium Arsenide (AlGaAs), Indium Phosphide (InP), Gallium Arsenide Phosphide (GaAsP), Aluminium Gallium Arsenide Phosphide (AlGaAsP), and/or Indium Gallium Arsenide Phosphide (InGaAsP).

4. An integrated optical device as claimed in any preceding claim, wherein the second material system is other than a III-V semiconductor material.

5. An integrated optical device as claimed in any preceding claim, wherein the second material system is selected from: Silica (SiO_2), Silicon (Si), Lithium Niobate ($NiNbO_3$), a polymer, or glass, any of which are optionally doped with optically active material.

6 An integrated optical device as claimed in any preceding claim, wherein the first device is or includes an optically active device.

7. An integrated optical device as claimed in Claim 6, wherein the optically active device is selected from one of: a laser diode, a light emitting diode (LED), an optical modulator, an optical amplifier, an optical switch or an optical detector.

8. An integrated optical device as claimed in any preceding claim, wherein the second device is or includes an optically passive device component.

9. An integrated optical device as claimed in Claim 8, wherein the optically passive device component comprises a passive waveguide.

10. An integrated optical device as claimed in any preceding claim, wherein the coupling region provides means for at least substantially mode matching between the first and second devices.

11. An integrated optical device as claimed in any preceding claim, wherein the first device provides the Quantum Well Intermixed (QWI) region.

12. An integrated optical device as claimed in Claim 11 when dependent upon Claim 10, wherein the mode matching means comprises a waveguide provided in the first device which waveguide is a tapered waveguide providing a linear change in width, a non-linear change in width, and/or a periodic or a-periodic segmentation.

13. An integrated optical device as claimed in any preceding claim, wherein the coupling region provides anti-reflection means at or near an interface between the first and second devices.

14. An integrated optical device as claimed in Claim 13 wherein the anti-reflection means comprises or includes an anti-reflection coating on a facet of the first device provided at the interface between the first and second devices.

15. An integrated optical device as claimed in either of Claims 13 or 14, wherein the anti-reflection means comprises or includes facets of the first and second devices provided at the interface between the first and second devices, the facets being formed at an acute angle to an intended direction of optical transmission.

16. An integrated optical device as claimed in any preceding claim, wherein a first waveguide section in the first device and optionally also a second waveguide section in the second device is/are bent.

17. An integrated optical device as claimed in any preceding claim, wherein the integrated optical device operates in a wavelength region of 600 to 1300 nm or of 1200 to 1700 nm.

18. An integrated optical circuit, optoelectronic integrated circuit, or photonic integrated circuit including at least one integrated optical device according to any of Claims 1 to 17.

19. An apparatus including at least one optical device according to any of Claims 1 to 17.

20. A method of providing an integrated optical device having hybrid integration of first and second devices formed in first and second different material systems comprising:

providing one of the first or second devices with a Quantum Well Intermixed (QWI) region at or adjacent a

coupling region between the first and second devices.

21 A method as claimed in Claim 21, wherein the Quantum Well Intermixed (QWI) region is formed in the first device by the steps of:

depositing on a surface of the first device a dielectric layer;

annealing the first device;

optionally removing the dielectric layer.

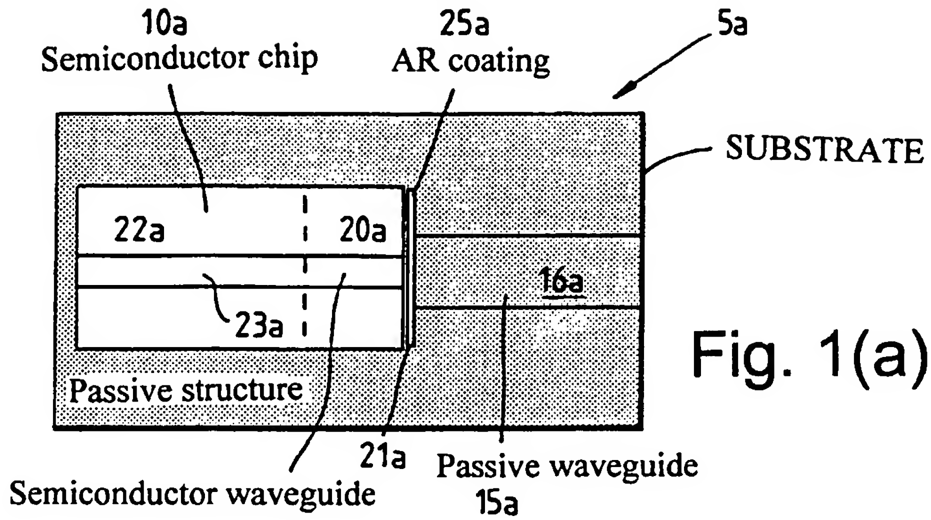

Fig. 1(a)

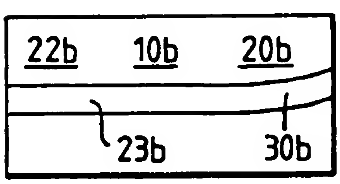

Fig. 1(b)

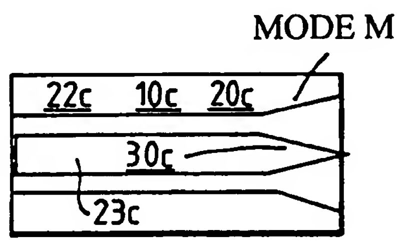

Fig. 1(c)

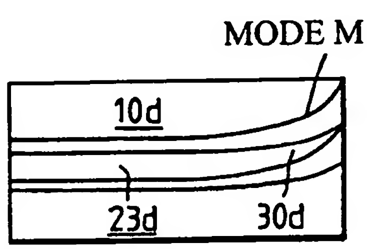

Fig. 1(d)

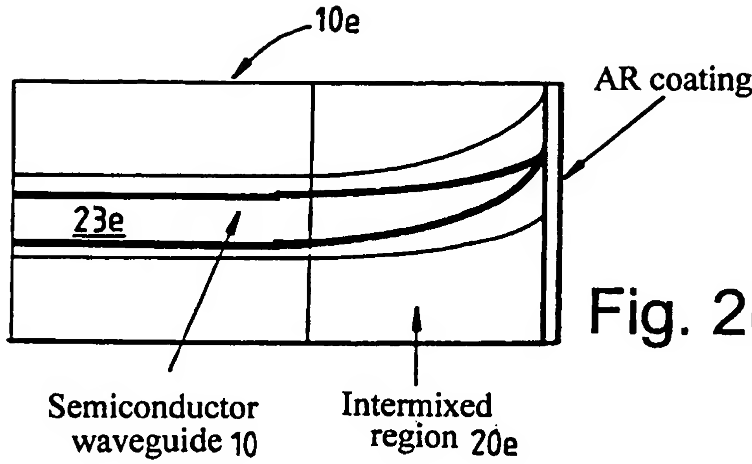
10e
AR coating
23e
Semiconductor waveguide 10
Intermixed region 20e

Fig. 2(a)

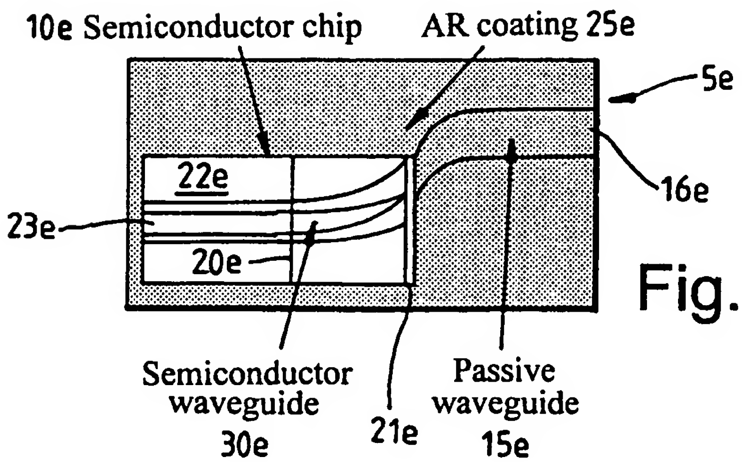
10e Semiconductor chip
AR coating 25e
5e
22e
16e
23e
20e
Semiconductor waveguide 30e
21e
Passive waveguide 15e

Fig. 2(b)

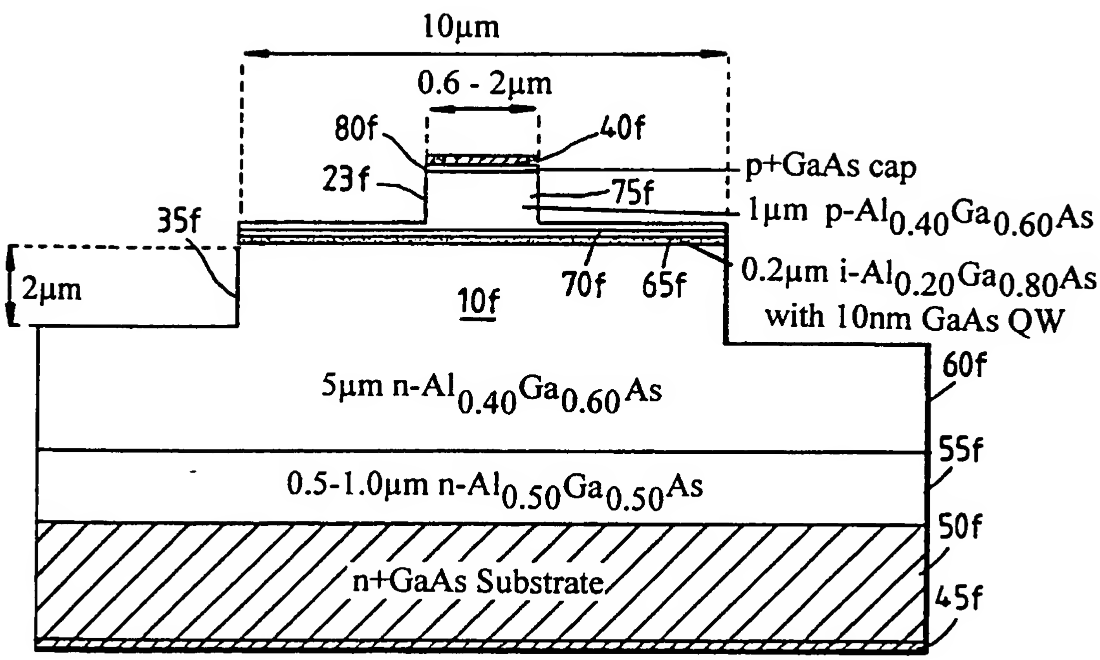
10μm
0.6 - 2μm
80f
40f
p+GaAs cap
23f
75f
1μm p-Al0.40Ga0.60As
35f
2μm
10f
70f
65f
0.2μm i-Al0.20Ga0.80As
with 10nm GaAs QW
60f
5μm n-Al0.40Ga0.60As
55f
0.5-1.0μm n-Al0.50Ga0.50As
50f
n+GaAs Substrate
45f

Fig. 3

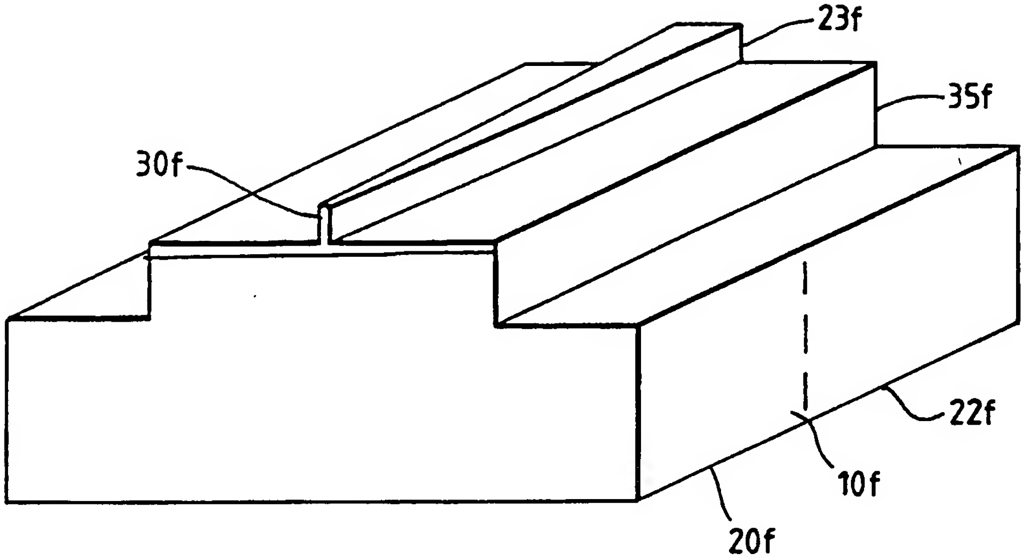

Fig. 4

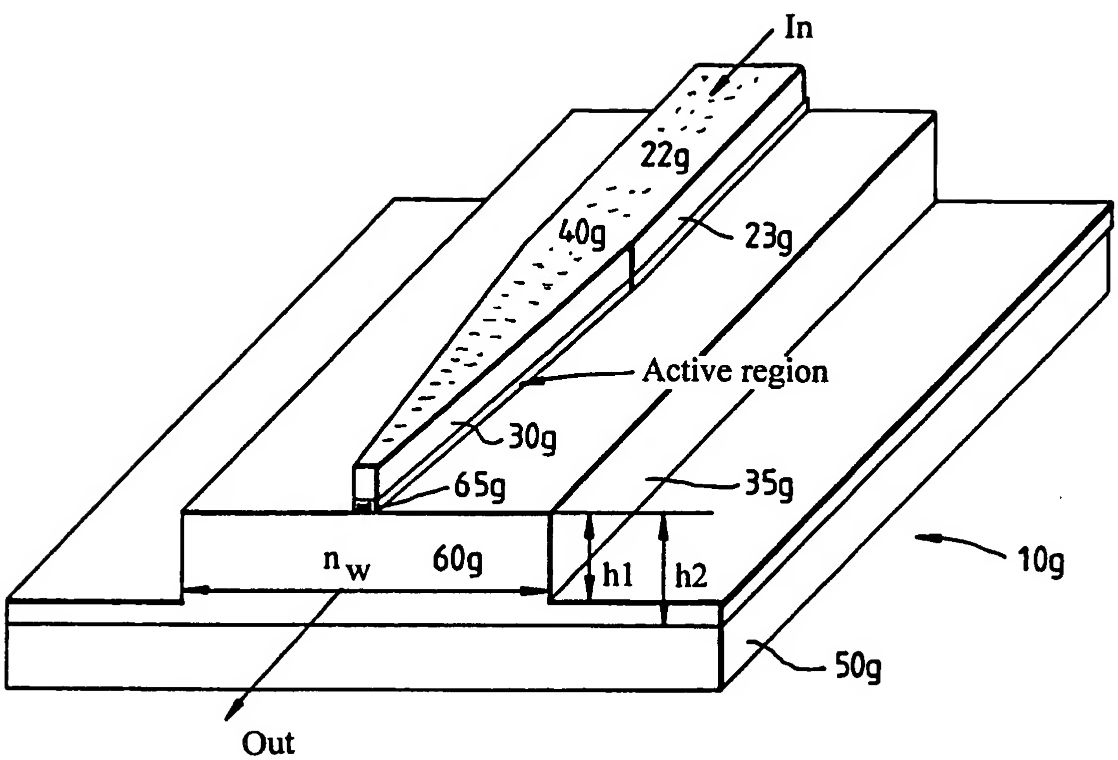
In
22g
40g
23g
Active region
30g
65g
35g
n_w
60g
h1
h2
10g
50g
Out

Fig. 5

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 01/00409

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G02B6/12

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 862 168 A (SCHILLING MICHAEL ET AL) 19 January 1999 (1999-01-19) abstract; figure 1 column 5, line 57 - line 67 column 6, line 5 -column 10 ---	1-3, 6-11, 18-21

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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Date of the actual completion of the international search: 6 July 2001

Date of mailing of the international search report: 23/07/2001

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Jakober, F

1

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
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A	MCDOUGALL S D ET AL: "Increased power operation of GaAs/AlGaAs waveguide p-i-n photodiodes with non-absorbing input facets, fabricated by quantum well intermixing" 1999 IEEE LEOS ANNUAL MEETING CONFERENCE PROCEEDINGS. LEOS'99. 12TH ANNUAL MEETING. IEEE LASERS AND ELECTRO-OPTICS SOCIETY 1999 ANNUAL MEETING (CAT. NO.99CH37009), 1999 IEEE LEOS ANNUAL MEETING CONFERENCE PROCEEDINGS. LEOS'99. 12TH ANNUAL MEETING, SA, pages 810-811 vol.2, XP002167408 1999, Piscataway, NJ, USA, IEEE, USA ISBN: 0-7803-5634-9 the whole document -----	1-22

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		US 6027989 A	22-02-2000

Form PCT/ISA/210 (patent family annex) (July 1992)